RESEARCH PAPER

Evaluation of Tree Forwarding by Farm Tractor in Patch Cutting of Poplar Plantations in Northern Iran

Seyed Rostam Mousavi · Mehrdad Nikooy

Abstract Time studies were conducted to quantify the productivity and the operational cost of log forwarding by farm tractor under the cut-to-length method for a poplar plantation located on even terrain in Shafaroud, northern Iran. Patch cutting was used as a silvicultural method. An empirical time study was conducted to evaluate farm tractor forwarding and the possibility of increasing the production rate. The elements of the forwarding work phase were identified and 30 forwarding cycles were recorded within the study. Models for effective time consumption, total productivity and work phases were calculated. The average load per cycle was 3.84 m^3, and the average one-way forwarding distance was 167 m. The average travel speed of unloaded tractor was 4.54 km/h, and the loaded speed 0.39 km/h. The average output was 3.6 m^3/effective hour and 3.44 m^3/gross effective hour, and the unit cost was 5.6 and 5.86 US\$/m^3. The cost and productivity resulting from this study showed the importance for foresters considering farm tractors as an appropriate method for log extraction in small-scale harvesting areas with a slope inclination <15 %.

Keywords Farm tractor productivity · Log forwarding · Manual felling · Time consumption

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Introduction

Wood extraction from forest to landing which is called primary transportation is one of the most time-consuming and expensive parts of harvesting activities (Mousavi 2009). Primary transportation can be done in several ways. The most common wood extraction method from cutting area to landing in the world is ground-based skidding and forwarding (forest haulage). In many regions of the world, farm tractors have been used in forestry where the terrain conditions and the size of the forest operation are not limiting factors. Using specialized logging attachments on modified farm tractors, farmers often extract logs during winter when their normal farming operations are suspended (Shaffer 2009). The forest industry pays a higher price for wood piled at roadside than it does for standing timber. If the logger can deliver wood to the roadside with his farm tractor logging system for less cost than other extraction systems, he can profit from doing his own harvesting.

In developing countries, mechanized harvesting machines are generally not favourable due to high capital investments and energy consumption, which is highly correlated with high fuel prices (Rodriguez 1986). Farm tractors, on the other hand, have very low initial costs and relatively low operating costs compared with specialized forest wood extraction machines. In developed countries farm tractor harvesting systems have also been used in forest operation in situations where they provide efficient operation and reduce environmental damage (Turk and Gumus 2010). Using a farm tractor for wood extraction from forests can be reasonable when the harvesting system is planned properly and directional felling is applied (Cadorette 1995).

A loaded tractor can travel on a skid trail with positive slope up to 15 % in normal conditions and can work on steeper slopes when special equipment is attached. Foresters prefer to use farm tractors wherever the logging area does not have enough timber for high investment in harvesting equipment. The main advantage of such tractors is high maneuverability and also availability.

Farm tractors can be used in various ways for log extraction. The common method for using a tractor in logging is cable skidding, other methods being grapple skidding and forwarding. Akay (2005) showed that in order to use a tractor for forwarding a trolley can be attached which can drag one end of a log on the ground or carry the log completely off the ground. It is advisable to use such equipment for distances over 1,000 m.

Farm tractor skidding is more prevalent than forwarding in Iran. A study by Gilanipoor (2012) showed that skidding cycle time using a farm tractor depends on slope, volume skidded, number of logs and terrain conditions. While numerous studies about skidding have been done in Iran, mostly for various kinds of skidders (Naghdi 1996, 2005; Javadpour 2006; Nikooy 2007; Mousavi 2009), and recently in small-scale operations with farm tractors (Gilanipoor 2012), little attention has been paid to log forwarding with farm tractors.

The prevalent method for productivity study is time study. Time consumption of cut-to-length harvesting is often applied to assess the main factors affecting work productivity and to establish a base for cost calculation and salaries or payments.

Accurate models may be utilized in various kinds of simulations that aim at finding new, more efficient work methods, and to optimize operations in timber harvesting.

A time study is usually done either as a comparative study, a correlation study, or a combination of both methods (Eliasson 1998). The objective of comparative studies is to compare two or several machines or work methods, while the objective of correlation studies is to describe the relationship between performance and the factors influencing the work (Bergstrand 1991). Time studies can be carried out using a continuous time study method, or repetitive timing or indirect work sampling (NSRF 1978; Samset 1990; Harstela 1991; Nurminen et al. 2006). Internal and external reliability describe ability of variables to provide information on the target of the study and accuracy of the results in predicting the parameter of the population of which the data are a sample, respectively (Harstela 1993). Standard time study is the main means to achieving time study results for generalization to other situations.

Because limited scientific information is presently available on applying the machine (farm tractor) under the conditions (patch cutting, small size trees, and low-slope terrain), the study is needed to identify the variables that influence the productivity and cost of farm tractor use, when forwarding logs from stump to roadside.

The aims of this study have been to: (1) to estimate the production rates (m^3/h) and costs (US\$/m^3) of harvesting operations using a farm tractor as a forwarder in a forest area with a slope up to 15 % slope; and (2) to develop a model for time consumption and productivity of forwarding by farm tractor, to determine the main factors influencing the harvesting phase.

The Study Sites

The study was carried out at the Shikhneshin plain in the Shafaroud forest, Guilan province, North Iran, between 37°20′N, and between 49°10′E (Fig. 1). The site is located in a plain with gentle slopes. The climate of the area is temperate; the average high temperature in summer is 28.9 °C and the average low temperature in winter is 4.4 °C. The study area is located at an altitude between 10 and 50 m above sea level.

The study area is covered by 65.1 ha of forest plantation (*Pinus taeda* and *Populus deltoides*). The trees had been planted at a spacing of 4 m × 3 m. The average stocking rate was 625 trees/ha. The poplar plantations in the region are cut after 25–30 years, and then replanted. The study was carried out in September 2010, when the trees had reached the target diameter and were ready for harvesting. Labeling of trees for harvesting was done in 2009, but trees were felled and delimbed in 2010. They were extracted by farm tractor via forwarding system. During the study the skid trail was dry and covered with leaves and branches of the felled trees.

The specifications of the tractor used for forwarding are provided in Table 1. Diameters of trees at breath height (DBH) were measured in sample plots before logging, and the average volumes were calculated using a local tree volume table. The skidder operators had several years of experience and the driver performed all machine services and most of the repair works.
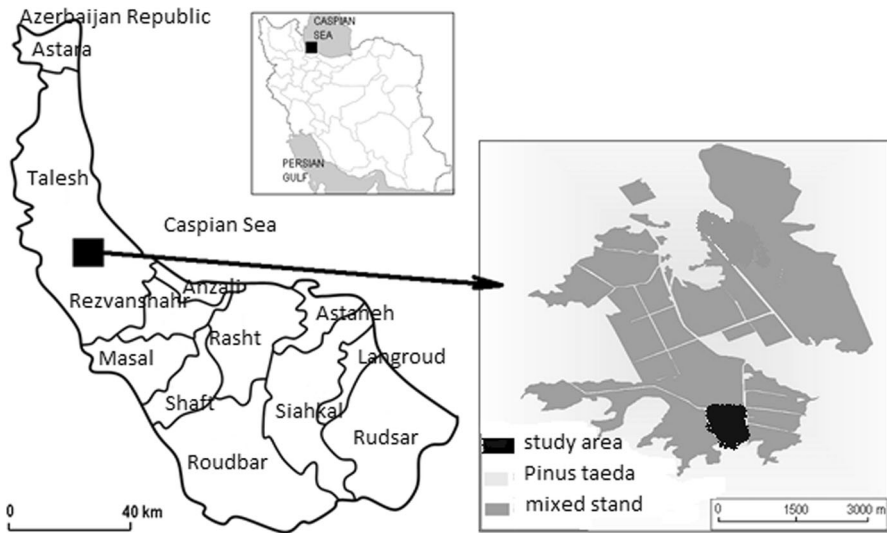
Fig. 1 Map of study area

The farm tractor forwarding phase can be divided into several elements. Driving empty begins when the tractor leaves the landing area and ends when the tractor stops at the working site. Collecting the logs starts when the worker loads the logs and ends when the loading is completed. Collecting time can also be divided in sub-elements including reaching the pile, lifting the logs, and locating and sorting the logs in the farm tractor trailer. Driving loaded starts when the full tractor moves towards the landing and ends when the tractor reaches the landing area. The last phase (unloading) commences when the tractor stops at the landing area, and ends when all logs are unloaded.

Table 2 shows the detailed time study results of the forwarding. The maximum number of logs per cycle was 100 which show the dimension of logs was small.

Research Method

During normal harvest operations, detailed records of operations were kept. A deci-minute stop watch was used for recording forwarding elements time. The Nordic Forest Work Study Council (NSR) time concept (as described by Harstela 1993) was used for data collection. Delays were recorded as technical, personal and operational delays (Fig. 2). Gross effective time means that delay times shorter than 15 min are included in the effective time.

Total effective times (without interruptions longer than 15 min) were recorded and mean log volumes per cycle were calculated and included in Eq. (2), yielding productivity per hour in each work phase. The volume of each log was calculated using Smalian's formula (Eq. 1) by multiplying the average cross-sectional area of the stem by the stem length (Ounekham 2009).

Table 1 Technical specifications of tractor model 8502 four-wheel-drive vehicle

Length	3.8 m	Weight	3,114 kg
Width	2.1 m	Power	75 hp
Height	2.52 m	Distance between two front wheels	1.35–1.94 m
Distance from the ground	0.36 m	Distance between two rare wheels	1.4–2.13 m
Engine power	80.5 kW	Fuel tank capacity	90 1

Table 2 Characteristics of timber extracted by farm tractor

Harvesting item	Forwarding
Study duration day (total observation time)	6
Total volume extracted (m³)	119.07
Avg. number of logs per cycle	63.2
Min. number of logs per cycle	25 0
Max. number of logs per cycle	100
Avg. diameter of logs (cm)	25.0
Avg. length (m)	1.20
Avg. distance (m)	167
Min. distance (m)	85
Max. distance (m)	250
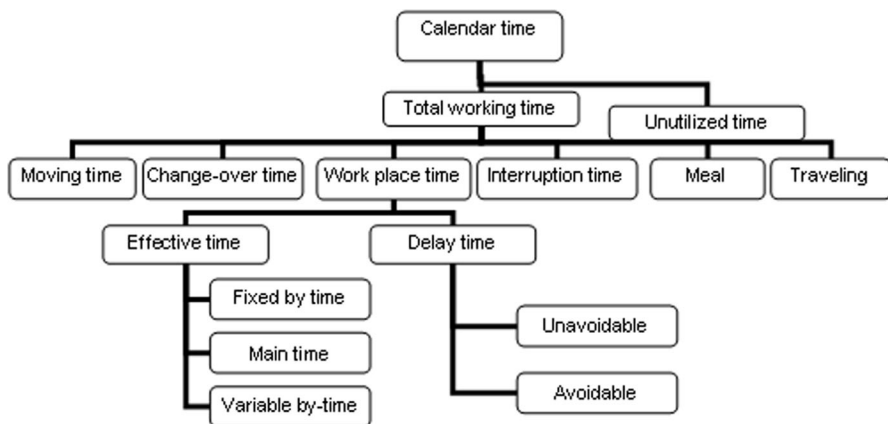
Fig. 2 Time concepts, according to the NSR recommendation. *Source*: Harstela (1993)

$$x_{vl} = \left(\frac{g_1 + g_2}{2}l\right) \tag{1}$$

Total effective time was converted into delay-free productivity and gross-effective productivity was calculated by using the formula (Eq. 3):

$$p_e = \frac{60x_{vl}}{t_{tot}} \tag{2}$$

$$p_{ge} = \frac{60x_{vl}}{t_{tot} + t_{delay}} \tag{3}$$

where x_{vl} = log volume (m^3), g_1 and g_2 = basal area at each end of log (m^2), l = log length (m), p_e = productivity (m^3/effective hour), p_{ge} = gross-effective productivity (m^3/gross-effective hour), t_{tot} = total time consumption (min/cycle), t_{delay} = delay times (min/cycle).

SPSS 18.0 for Windows was used for data analysis. Multivariate regression was used for modeling. Two techniques were utilized to create a model for time consumption. Firstly, the work phase based model (a delay-free time consumption model) was formed separately for each element of the work phase. The time consumption model was created by combining the forwarding phase elements. In the other technique, overall time consumption was regressed against independent variables. The P value, F-value and coefficient of multiple determination (R^2) were chosen as statistical criteria for selecting the best-fit model. The P value represents the level of significance of the statistical test. If the p-value is <0.05, then the regression model is statistically significant. Stepwise regression was applied because it has the ability to recheck the t values corresponding to the independent variables that were previously entered in the regression equation (Mendenhall and Sincich 1996). The Kolmogorov–Smirnov test (K–S) test was used to determine if the dataset is normally distributed. The factor analysis was used to find statistically the most important proportion of the time consumption among elements of work phase.

The primary testing tool for validity of the results is graphical residual analysis. Various types of plots of the residuals from a fitted model provide information on the accuracy of different aspects of models. Another technique was using the confidence interval of the model which was produced in the SPSS output. In this technique, at least two cycles of observations were set aside randomly for modeling. The data were used later for validity procedure.

Both fixed and variables costs were estimated for the farm tractor. Total costs were calculated by totaling machine and labour cost (Table 3). Fixed costs included costs for interest, depreciation, tax and insurance. The interest rate was 16.5 %. Depreciation was calculated assuming a tractor economic life of 5 years. The fuel consumption rate was calculated as below (Eqs. 4, 5):

$$F_c = gkw \cdot x_1 \cdot CL \tag{4}$$

$$OGC = \frac{gkw \cdot x_2}{100} \tag{5}$$

where OGC = oil and grease cost, gkw = engine power (hp), CL = fuel cost (US$/l), x_1 = 0.18 for diesel oil, and x_2 = 0.2 for tractor, skidder, front-end loader and trucks.

Results

Distribution of Time Consumption

The time distribution of the forwarding elements with the farm tractor is presented in Fig. 3a. Travel loaded took the longest time, followed by collecting the log and

delay. Figure 3b shows the time distribution of various kinds of delay. Only 3 % of total time consumption was related to delay and the rest of the time was effective time. The eigen-value for driving empty, collection time, travel loaded, unloading and delay was 38.57, 23.05, 19.31, 15.85 and 3.1, respectively. In addition, the cumulative percentage of total variance by these main variables (except delay time) was 96.8 %.

Time consumption for work phase:

1. Driving empty

   The time consumption for driving empty was found to depend on the driving distance and driving speed according to the equation (Eq. 6).

   $$t_1 = 2.437 - 0.0468x_{es} + 0.013x_{fd} \qquad (6)$$

   where $t_1 = $ time consumption for driving empty, min/cycle $x_{es} = $ driving empty speed $x_{fd} = $ forwarding distance

2. Collecting time

   Time consumption for collecting and loading time was found to depend on number of logs per load (Eq. 7).

   $$t_2 = 14.152 + 0.179\ x_n \qquad (7)$$

   $t_2 = $ time consumption for collecting logs and loading, min/cycle $x_n = $ number of logs

3. Travel loaded

   Time consumption of travel loaded was found to depend on diving speed (Eq. 8).

   $$t_3 = 35.894 - 44.713x_{fs} + 0.068x_{fd} \qquad (8)$$

   where $t_3 = $ time consumption for travel loaded, min/cycle $x_{fs} = $ driving loaded speed

4. Unloading

   Time consumption for travel unloaded is calculated as a mean value. The average time consumption of unloading was 12.5 min/cyle. Time consumption of unloading did not depend on tree species and other variables.

Overal Time Consumption and Productivity Model

Overal time consumption and delay free productvity is calculated according to the fomulas (Eqs. 9, 10).

$$t_o = 45.4 + 0.438x_n \qquad (9)$$

$$p_e = 1.94 + 0.892x_v - 0.03x_n \qquad (10)$$

$t_o = $ overal time consumption (min/cycle) $p_e = $ productvity of forwarding (m^3/effective hour)

Descriptive statistics of various elements of farm tractor forwarding are presented in Table 4. The mean time value of unloading is used for constructing

Table 3 Summary of detailed machine cost calculation parameters

Cost factor	Level	Cost factor	Cost
Purchase price (US$)	16,300	Annual interest (US$)	2,282
Salvage value (US$)	4,075	Annual depreciation (US$)	2,445
Economic life (years)	5	Annual tax and insurance(US$)	472
Tyre life (h)	3,000	Total fixed cost (US$/PMH)	5.8
Tyre price (US$)	200(F)	Repairs and maintenance ($/PMH)	1.47
	800(R)		
Number of tyres	6	Fuel and lubricate cost (US$/h)	4.82
Repair factor or f	0.9	Tyre cost (US$/h)	2.9–3.3
SMH (h/year)	1,200	Total variable cost (US$/h)	6.33
PMH (h/year)	900	Total labour cost (US$/h)	9.6
Utilization, % Ut = (PMH × 100/SMH)	75 %	Total cost (US$/h)	21.7

SMH scheduled machine hour, *PMH* productive machine hour
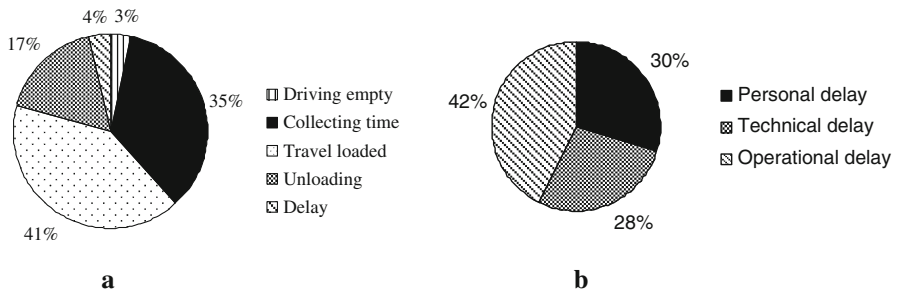
Fig. 3 Distribution of time consumption in farm tractor forwarding (**a**) and delays (**b**)

total time consumption model where it does not depend on any variables. Statistical analysis showed that there is a significant differences between various time consumption elements of forwarding ($P < 0.05$).

The average, maximum and minimum time consumption and productivity of forwarding with and without delay are summarized in Table 5. The average delay-free time consumption of forwarding was 3.8 % less than in time consumption with delay, while the average delay-free productivity was 4.17 % higher than in productivity considering delay. Productivity has been calculated based on productive machine hours (PMH). Gross effective time is calculated based on PMH but delay <15 min is included in the calculation.

The statistical characteristics of the regression models for forwarding are presented in Table 6. F and *P* values are statistically significant; however, the coefficient of the determination is low which shows that the model only partially explains time variations.

The effect of two of the most important variables in forwarding (log volume and number of logs) on forwarding productivity is illustrated in Fig. 4. A negative

Table 4 Descriptive statistics of mean value based work phase model

Work phase	Parameter (min)	Mean min/cycle	Min min/cycle	Max (min/cycle)	SD	N
Driving empty	*t_1	2.4	1.2	4.1	0.8	30
Collecting time	t_2	25.5	7.2	39.5	8.4	30
Travel loaded	t_3	30	8.2	60.3	10.2	30
Unloading	t_4	12.5	3.2	19.2	4.1	30

*t values represent time consumption for work phase (min/cycle)

relationship between productivity and number of logs and a positive relationship with volume extracted is found. Therefore the highest productivity is found when the number of logs is low, and the volume forwarded is high.

Production Cost

Unit cost of tractor forwarding increases by 4.2 % when delay time is included in the calculation. The differences between maximum (11.46) and minimum unit cost of farm tractor forwarding was 9.7 US$/m^3 (Table 7).

Discussion

The results of this study can be applied in terrain with up to 15 % slope in summer periods with dry weather conditions. Because the trees were small to medium in size (maximum diameter 40 cm), the stem size was not a hindering factor for manual loading and unloading. Unskilled workers just carry logs to the tractor, but this can be tedious work. Loading the tractor manually may influence the speed of work but using special devices for loading is not justified financially, because there is not enough work for a machine.

Methodologically, the emphasis of this study was put on the correlation time study. The main problem associated with correlation studies is the multiplicity of influencing factors which are controlled by the detailed division of harvesting work phases into elements (Bergstrand 1991; Nurminen et al. 2006).

According to Harstela (1993), the productivity of a harvesting system is a function of the qualities of the labour force (effort, skill, physical capacities, age, feeding quality and motivation), terrain condition, and machinery availability. One of the main problems regarding the generalization of the study is related to labour force, especially in a system where manual work has a crucial effect on production. Therefore, in this study, a standard crew or normal workers was used to minimize the influence of the workers on the results. This is an important approach to improve the ability to generalize the study results (Harstela 1993; Nurminen et al. 2006).

Two techniques were applied to create the models, these being work-phase-based model and overall time consumption model. The advantage of developing a work-phase-based model was, above all, the possibility of observing the harvesting work

Table 5 Productivity of forwarding within the study area

Harvesting item	Effective time	Gross effective time
Avg. forwarding time (min/cycle)	70.4	73.06
Min. forwarding time (min/cycle)	33.0	36.4
Max. forwarding time (min/cycle)	107.3	109.4
Avg. forwarded volume (m^3)	3.84	3.84
Min. forwarded volume (m^3)	1.30	1.30
Max. forwarded volume (m^3)	6.80	6.80
Avg. productivity (m^3/h)	3.59	3.44
Min. productivity (m^3/h)	1.11	1.07
Max. productivity (m^3/h)	11.46	10.49

in greater detail, to decrease the variation of time consumptions as well as to reduce the number of influencing factors (Nurminen et al. 2006; Mousavi 2009).

Statistically, the standardized residuals of the models were normally distributed. According to the levels of the coefficients of determination and the results of F-test, all models proved to fit the observation ($P < 0.05$).

Extraction distance is one of the main factors that influences the productivity and cost of any harvesting system, as has been reported in several studies (e.g., Feghhi 1989; Eghtesadi 1991; Naghdi 1996, 2005; Akay 2005; Nikooy 2007). However, in the study reported here distance did not enter in the constitution of the model as an important variable. The variation observed in the time consumption and productivity in each cycle was mostly related to other variables including the number of logs and log volume. Similar results have been found in the other studies (e.g., Naghdi 2005; Akay 2005; Nikooy 2007).

Driving empty was modeled, and was highly dependent on the forwarding distance. Driving empty took 3 % of the forwarding time. Collecting time was about 35 % of the total time consumption and was influenced by the number of logs and volume per cycle. Travel loaded is the most time consuming element of forwarding. Travel loaded is related to volume forwarded and the number of logs. Similarly to other harvesting work phases, time consumption of tractor forwarding involves delay times. Three kinds of delays were considered in forwarding. Operational delay and technical delay accounted for almost 70 % of the delay time. Personal delay accounted by 30 %, which can be decreased with improving supervision. In general, delay time took only 4 % of the forwarding time, which is not statistically a significant proportion of the total time consumed based on calculated eigen-values (3.1) in the factor analysis. Overall time consumption of forwarding was modeled using a regression equation as a function of statistically significantly independent variables: number of logs per cycle, forwarding distance, and volume per cycle. Other variables were not statistically significant.

High productivity can be obtained in dry and flat terrain conditions with suitable load-bearing capacity. According to Session (2007), even a small gradient may have a negative influence on productivity. The maximum manageable adverse gradient for a loaded vehicle ranges from 6 to 8 % (Session (2007). The production rate for

Table 6 Statistical characteristics of models based on regression analysis

Model	Dependent variable	R^2	F-test		N	Term	Constant/coefficient	Estimated SE	t test	
			F-value	P					t value p	P
Driving empty	t_1	0.88	105.25	<0.001	30	Constant	2.437	0.258	9.432	<0.001
						x_{es}	−0.468	0.034	−13.67	<0.001
						x_{fd}	0.135	0.001	8.49	<0.001
Collecting time	t_2	0.226	8.45	<0.001	30	Constant	14.152	4.124	3.431	0.002
						x_{nl}	0.179	0.062	2.908	0.007
Travel loaded	t_3	0.215	7.93	0.009	30	Constant	16.5	3.288	0.96	0.003
						x_n	0.212	2.81	9.049	0.009
Overall	t_{ot}	0.28	11.28	0.002	30	Constant	45.4	8.7	5.21	<0.001
						x_{nl}	0.438	0.13	3.36	0.002
Productivity	p_e	0.77	47.46	<0.001	30	Constant	1.94	0.854	2.279	0.030
						x_v	0.892	0.114	7.796	<0.001
						x_n	−0.031	0.009	−3.293	0.003

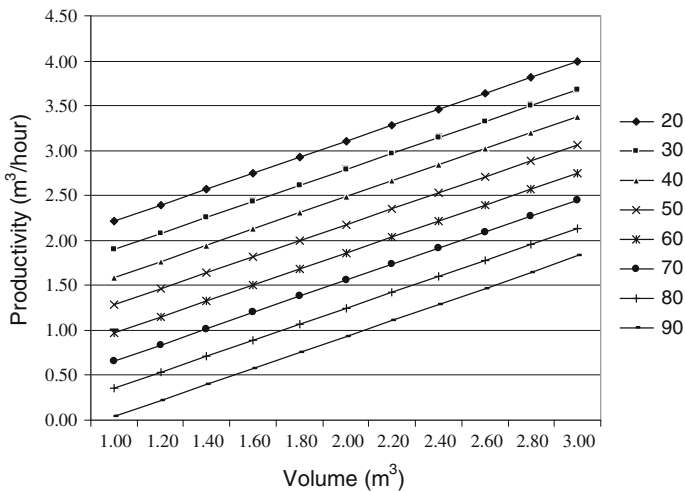x_{fd} = forwarding distance, x_{es} = driving empty, x_{nl} = number of logs

Fig. 4 Productivity of forwarding as a function of number of logs and volume loaded in the study

Table 7 Unit cost of tractor forwarding

Unit cost	Max. unit cost (US$/m^3)	Gross-effective time
Avg. unit cost (US$/m^3)	5.62	5.86
Min. unit cost (US$/m^3)	1.76	1.92
Max. unit cost (US$/m^3)	1.76	18.84

farm tractor forwarding in the study was 3.59 m^3 per effective hour (range 1.11–11.1 m^3) which was 47 % higher than in Gilanipoor's (2012) study using the same type of tractor, but with logs skidded on steeper slopes. In the study by Spinelli and Magagnotti (2012), the production rate was 4 m^3 per SMH which is 10 % higher than in this study. In comparison to use of a skidder in the same area, the production rate was 46 % lower than when using a cable skidder (a Timberjack 450C) and about 50 % lower than with grapple skidder (HSM-904) (Mousavi et al. 2012). Productivity in this study was similar to that reported by Turner et al. (1988). Overall production rate of farm tractor logging can be compared to that of crawler tractor logging where the speed of vehicle for log extraction is low, which keeps productivity low. Magagnotti and Spinelli (2011) reported a productivity of 2.3 m^3/h and an average load of 0.8 m^3 per cycle with a crawler tractor. Zecic and Marence (2005) indicated a productivity of 2.4 m^3/h and an average load of 1.1 m^3 for a mini-skidder (Ecotrac 55V).

The operating cost is one of the most important issues using any wood extraction machine. The operating cost of the system was US$ 21.5/PMH, which is 43 % lower than in the study by Spinelli et al. (2004), 30 % higher than in a study by Drake-Brockman (1999), and 3.7 % higher than in the study by Turner et al. (1988). The production cost of cable skidding and grapple skidding was 3.7 and 2.3 times as high as in this study, respectively (20.7 and 12.8 vs. US$ 5.6/PMH).

Models introduced in this study can be used in planning, work optimization, and production and cost estimation under similar working conditions to those experienced in this study. Nowadays, various types of machines are used for working in the forest. Knowledge about the characteristics of each of them helps in choosing the most appropriate machine and method for wood extraction. The use of farm tractors by forest wood companies in forest plantations provides an opportunity to calculate the production rate and costs, to identify the most variables having the greatest impact on wood extraction, and to compare farm tractor with other machines.

Conclusions

Forest resources in many part of the world are depleted due to applying various silvicultural methods such as clear-cutting and shelter wood method (the method provides a source of seed and shelter for seedling and sapling with keeping old trees in the forest), and therefore patch cutting and single tree selection method is used as an alternative. Limited wood removal in the single tree selection method leads to perform operations with less costly machines than in sophisticated one such as skidder and forwarder. Logging with a farm tractor has only 8 % of initial investment in comparison with using a skidder and has relatively low operating costs (US\$ 5.86 vs. US\$ $9.5/m^3$). It has been found that log volume and number of log are the most influencing variables on farm tractor forwarding. Farm tractor logging can be limited by some factors including the terrain conditions, ground slope, and timber size. This study demonstrates that in small forest areas with small tree diameters in a suitable terrain condition, farm tractors work efficiently.

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